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Research Report

Submitted by

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ABSTRACT

The band width of a knife-edge scatter circuit is estimated as a function of the antenna beam width. The knife edge is assumed to be located off to one side of a line between the transmitter and receiver as in the Monterey- San Jose circuit, but is assumed to be in a plane with this line.

It is shown that where the effective knife edge is small compared to the beam width, the signal may be completely cancelled at the receiver. This cancellation can best be avoided by moving one antenna a lateral distance that is calculated.

On the basis of the equations developed in this report the band width between nulls of the Monterey- San Jose microwave circuit was calculated to be 2.6 Mc. The measured bandwidth was 3.4 Mc.

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DOG LEG KNIFE EDGE SCATTER CIRCUIT

Figure 1 shows the geometry involved in a dog-leg knife edge scatter circuit. The reflecting knife edge, AB, is assumed to be uniformly illuminated, and may be taken approximately to be the length illuminated by the narrower of the two beams (narrower at the knife edge) between its half-power points. The difference between the lengths of the longest and shortest signal paths is seen from the figure to be $s_1\theta_1(\sin \beta_2/\cos \beta_1 + \tan \beta_1)$.

The signal in the receiving antenna is the sum of signals received from the various portions of the knife edge and the components are assumed to be of equal strength per unit length of the knife edge, and the phase is assumed to vary uniformly along the knife edge (small beam angle). The received signal strength is therefore proportional to

$$\left| \int_0^{\phi m} e^{j\phi} d\phi \right|$$

where ϕ_m is the phase difference between the longest and shortest paths. The received signal strength is therefore proportional to $|\sin \phi_m/2|$. Now ϕ_m is proportional to frequency, so the received signal varies as $|\sin kf|$ as plotted in Figure 2. The circuit bandwidth, Δf, is here taken to be the separation between nulls in Figure 2. The actual bandwidth will be somewhat less than this depending on signal-to-noise ratio and the type of modulation used.

For a null frequency f_1 the maximum path difference equals an integral number of wavelengths, or

$$s_1\theta_1(\tan \beta_1 + \sin \beta_2/\cos \beta_1) = n\lambda_1 = nc/f_1$$

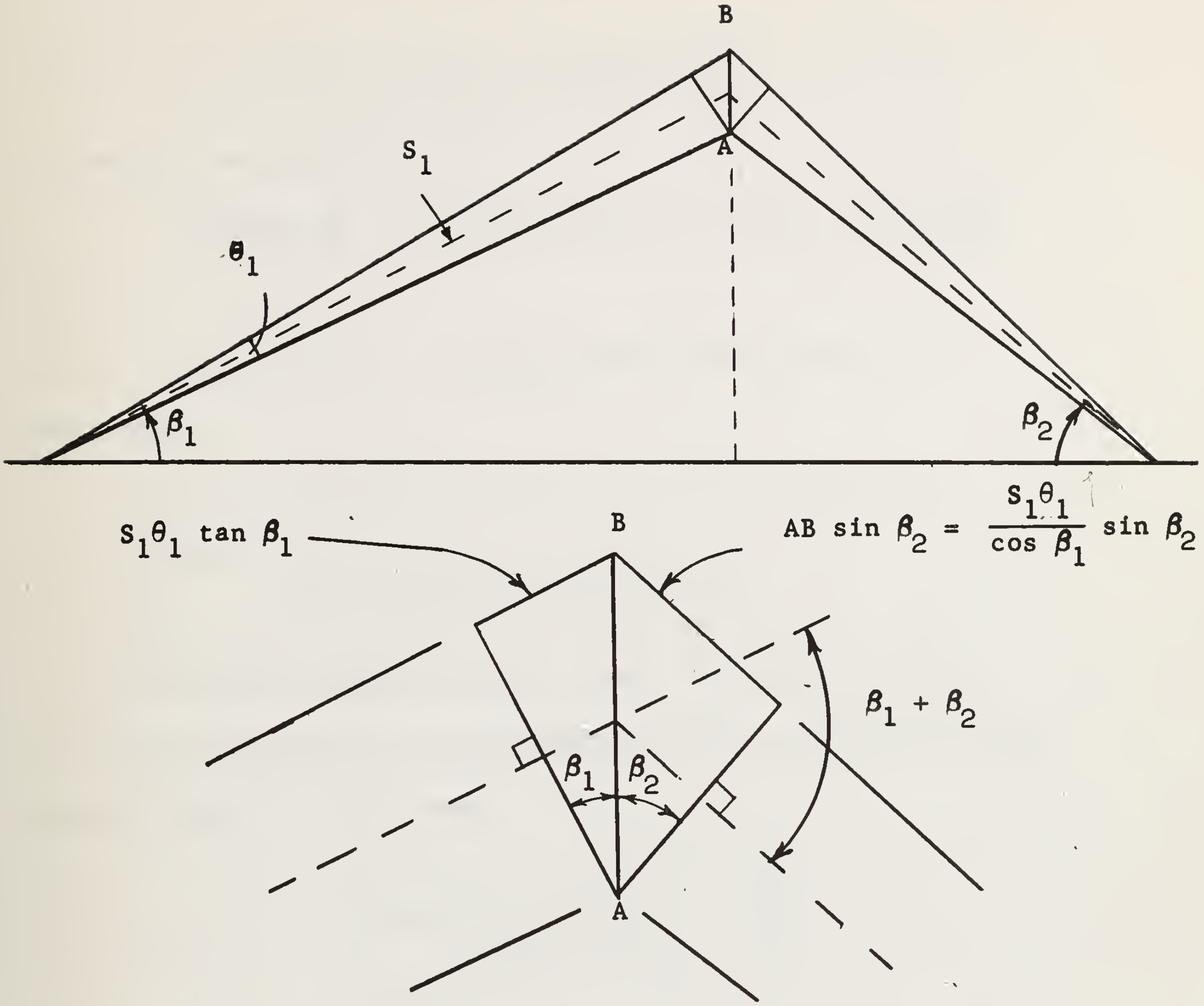

Figure 1. Path Geometry

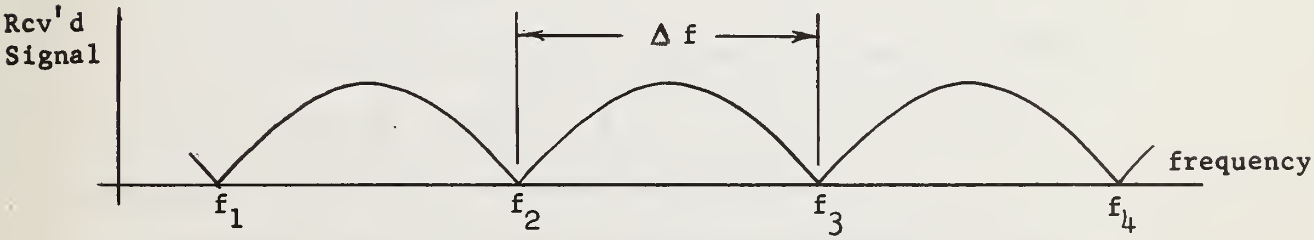

Figure 2. Signal strength vs. frequency

or

$$f_1 = nc/s_1\theta_1(\tan \beta_1 + \sin \beta_2/\cos \beta_1)$$

At the next null, $f_2 = f_1 + \Delta f$

$$s_1\theta_1(\tan \beta_1 + \sin \beta_2/\cos \beta_1) = (n + 1)\lambda_2 = \frac{(n + 1)c}{f_1 + \Delta f}$$

or

$$f_1 + \Delta f = (n + 1)c/s_1\theta_1(\tan \beta_1 + \sin \beta_2/\cos \beta_1)$$

subtracting,

$$\boxed{\Delta f = \frac{c}{s_1\theta_1(\tan \beta_1 + \sin \beta_2/\cos \beta_1)}}$$

It has been assumed that θ_1 is small so that $\theta_1 \approx \sin \theta_1$. If, moreover, both β_1 and β_2 are small, $\tan \beta_1 \approx \beta_1$, $\sin \beta_2 \approx \beta_2$, and $\cos \beta_1 \approx 1$. In this case

$$\boxed{\Delta f \approx \frac{c}{s_1\theta_1(\beta_1 + \beta_2)}}$$

It is seen in this case that the bandwidth depends only on the angle between the lines of sight, $(\beta_1 + \beta_2)$, the beam width of the narrower beam, θ_1, and the distance s_1, and is independent of carrier frequency in any case.

Now calculate the beam width of the Monterey- San Jose circuit from the above equation. Use $\beta_1 + \beta_2 = 6.7^\circ$ $s_1 = 10.0$ miles = 16,090 meters; $\theta_1 = 3.5^\circ$. We obtain $\Delta f = 2.6$ Mc.

It would be useful to test the validity of the above theory. One method would be to use very wide-band modulation at the transmitter with a wide-dispersion spectrum analyzer at the receiver.

Another obvious method would be to vary the frequency of the transmitter at a relatively slow rate. It is to be expected that the characteristics of the received signal will differ from the calculations primarily because of the diffuse knife edge on the actual path, but that there may be appreciable correlation. The positions of the nulls can be expected to vary with propagation conditions, antenna orientation, and antenna location. Both space and frequency diversity should be useful in overcoming the effects of shifting nulls. It may be found that with space diversity antenna #2 should be oriented for maximum signal during a fade of this type at antenna #1, particularly if the spacing between antennas is relatively small. In cases where a channel width is available that is much greater than the information bandwidth, frequency diversity could be obtained in a single transmitter through the proper choice of modulation techniques such as by the use of one or more subcarriers in addition to the main carrier.

Note that the null frequencies can be changed by changing the orientation of that antenna located closer to the knife edge. The apparent direction of arrival of a signal of given frequency may therefore be different at different locations-- even for two receiving antennas located quite close together as at San Jose. If the frequency is changed, the apparent direction of arrival of the signal can be expected to change.

SHORT KNIFE EDGE

A special case of interest occurs on a path where the knife edge visible from both transmitter and receiver subtends an angle less than the beam width of the antenna closer to it, or narrower than the beam width of either antenna. For purposes of discussion we will assume that the knife edge fills only a fraction of the width of the beam of the receiving antenna. For a fixed receiving antenna location it is quite possible that the frequency used will be at one of the nulls shown in Figure 2. The null could be avoided by (a) changing the transmitter frequency, (b) by rotating the receiver antenna in order to illuminate the knife edge nonuniformly in the side of the beam, or (c) by moving the receiving antenna. The frequency cannot always be changed, and illuminating the knife edge in the side of the beam is inefficient, so it is desirable to know how far the antenna might have to be moved laterally to go from a null to a position of maximum signal strength. If this distance is small, provision might be included in the antenna mount for lateral movement.

Referring to Figure 1, we shall have a maximum received signal strength if the maximum path difference equals an odd number of half wavelengths, or

$$AB(\sin \beta_2 + \sin \beta_1) = (n + 1/2)\,\lambda$$

or

$$AB(\beta_1 + \beta_2) \approx (n + 1/2)\,\lambda \qquad (\beta_1 \ll 1;\ \beta_2 \ll 1)$$

The adjacent maximum occurs where

$$AB(\beta_1 + \beta_2 + \Delta\beta_1) = (n + 3/2)\,\lambda$$

Therefore

$$AB\,\Delta\beta_1 = \lambda$$

The lateral distance between adjacent points of maximum signal strength is $s_1\Delta\beta_1$, or

$$s_1\Delta\beta_1 = \frac{s_1\lambda}{AB}$$

For example, if $\lambda = 0.15$ meters, $s_1 = 19{,}200$ meters, and AB = 600 meters, the adjacent maxima are separated by 5.1 meters, and a lateral motion of this amount would be required to ensure that the antenna could be located at a point of maximum signal strength.

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